

A New SU UMa-Type Dwarf Nova, QW Serpentis (= TmzV46)

Daisaku NOGAMI

*Hida Observatory, Kyoto University, Kamitakara, Gifu 506-1314
nogami@kwasan.kyoto-u.ac.jp*

Makoto UEMURA, Ryoko ISHIOKA, Hidetoshi IWAMATSU, Taichi KATO

Department of Astronomy, Faculty of Science, Kyoto University, Sakyo-ku, Kyoto 606-8502

Elena P. PAVLENKO

*Crimean Astrophysical Observatory, Nauchny, 98409 Crimea
Isac Newton Institute of Chile, Crimean Branch, Ukraine*

Alex BAKLANOV

Department of Astronomy, Odessa National University, T. G. Shevchenko park, Odessa 65014, Ukraine

Rudolf NOVÁK

Nicholas Copernicus Observatory, Kravíhora 2, Brno 616 00, Czech Republic

Seiichiro KIYOTA

Variable Star Observers League in Japan (VSOLJ), 1-401-810 Azuma, Tsukuba, Ibaraki 305-0031

Kenji TANABE

Department of Biosphere-Geosphere Systems, Faculty of Informatics, Okayama University of Science, 1-1 Ridaicho, Okayama 700-0005

Gianluca MASI

Physics Department, University of Rome "Tor Vergata" Via della Ricerca Scientifica, 1 00133 Rome, Italy

Lewis M. COOK

Center for Backyard Astrophysics (Concord), 1730 Helix Court, Concord, CA 94518, USA

Koichi MORIKAWA

VSOLJ, 468-3 Satoyamada, Yakage-cho, Oda-gun, Okayama 714-1213

Patrick SCHMEER

Bischmisheim, Am Probstbaum 10, 66132 Saarbrücken, Germany

(Received 2002 0; accepted 2002 0)

Abstract

We report on the results of the QW Ser campaign which has been continued from 2000 to 2003 by the VSNET collaboration team. Four long outbursts and many short ones were caught during this period. Our intensive photometric observations revealed superhumps with a period of 0.07700(4) d during all four superoutbursts, proving the SU UMa nature of this star. The recurrence cycles of the normal outbursts and the superoutbursts were measured to be ~ 50 days and 240(30) days, respectively. The change rate of the superhump period was -5.8×10^{-5} . The distance and the X-ray luminosity in the range of 0.5-2.4 keV are estimated to be 380(60) pc and $\log L_X = 31.0 \pm 0.1$ erg s $^{-1}$. These properties have typical values for an SU UMa-type dwarf nova with this superhump period.

Key words: accretion, accretion disks — stars: novae, cataclysmic variables — stars: dwarf novae — stars: individual (QW Ser)

1. Introduction

Cataclysmic variable stars (CVs) are a group of binary stars consisting of a white dwarf (primary star) and a late-type secondary star (for a thorough review, Warner 1995a). Surface gas of the secondary pouring out from its Roche lobe via the inner Lagrange point is transferred to the primary. The gas is accreted by the white dwarf through an accretion disk in usual CVs.

Dwarf novae are a class of CVs, repeatedly showing large amplitude variations of brightness (2–8 mag) due to changes of the physical status of the accretion disk. SU UMa-type dwarf novae, which originally defined by (Warner 1985), give rise to two types of outbursts: normal

outbursts and long lasting superoutbursts. Superhumps are small-amplitude modulations characteristic to SU UMa stars which are observed only during the superoutburst. Prograde precession of the eccentric accretion disk due to the tidal influence has been attributed to the cause of the superhump phenomenon (Whitehurst 1988). The thermal-tidal disk instability model is the currently standard model for the dwarf nova-type outbursts, and has succeeded in reproducing the basic properties of various types of the brightness variation in dwarf novae including SU UMa stars (for a review, see Osaki 1996; for an example of two-dimensional simulations, Truss et al. 2001). Observations of dwarf novae are, however, still producing problems which challenge the 'current' model.

QW Ser was discovered by Takamizawa (1998) who detected four positive detections in his photographic film collection. He designated this variable star as TmzV46, and suggested it to be a possible dwarf nova, based on its blue color in the USNO A1.0 catalog. Schmeer (1999) detected an outburst at 1999 Oct. 4.114 (UT), confirming the dwarf nova classification. Tracing this outburst, Kato, Uemura (1999) revealed that the outburst duration was between 11 d and 16 d and the decline rate was 0.10 mag d^{-1} . Kazarovets et al. (2000) finally gave TmzV46 the permanent variable star name, QW Ser.

QW Ser is identified with USNO B1.0 0983-0296263 ($B1 = 17.57$, $R1 = 17.44$, $B2 = 18.20$, $R2 = 17.42$). The proper motion of this star is listed as $(\mu_{\text{R.A.}}, \mu_{\text{Dec}}) = (-4(2), -40(2))$ in a unit of mas yr^{-1} . QW Ser is also identified with the X-ray source 1RXS J152613.9+081845 (Voges et al. 2000), which has a 52–201 keV count rate of $0.045(18) \text{ count s}^{-1}$.

We in this paper report on our observations during four long outbursts in 2000, 2001, 2002, and 2003, which unveiled the SU UMa nature of QW Ser. The next section mentions the observations, and the section 3 describes the details of our observational results. The characteristics of QW Ser will be discussed in the section 4.

2. Observation

The observations were carried out at nine sites with ten sets of instruments. The log of the observations and the instruments are summarized in Table 1. Figure 1 is a finding chart where the local comparison stars used are marked.

The Kyoto and Okayama frames were processed by the PSF photometry package developed by one of the authors (TK) after dark-subtraction and flat-fielding. All the frames obtained at Hida were reduced by the aperture photometry package in IRAF¹, after de-biasing and flat-fielding. All frames obtained at the CBA Concord and Rome were reduced by aperture photometry after dark subtraction and flat-fielding, using the AIP4WIN software by Berry and Burnell² and the QMiPS32 software, respectively. The Crimean images were dark-subtracted, flat-fielded, and analyzed with the profile/aperture photometry package developed by Vitalij P. Goranskij. PSF photometry of the Brno data were performed, using the package Munidos³ which is based on Daophot II.

The magnitude scale was calibrated using the Henden&Sumner sequence,⁴ and all the data were adjusted to match the V-band data obtained at Tsukuba and Crimea. The heliocentric correction was applied to the observation times before the following analyses.

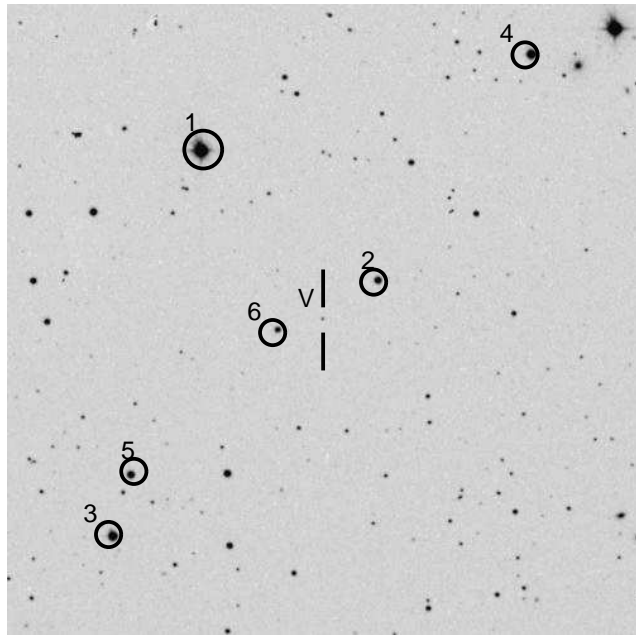


Fig. 1. Finding chart of QW Ser generated by the astronomical image-data server operated by the National Astronomical Observatory of Japan, making use of Digital Sky Survey 2. North is up, and East is left. The comparison stars used are given their numbers, which are identical with those in Table 1.

3. Result

The campaigns of time-resolved photometry were conducted during four superoutbursts which occurred in 2000 July, 2001 February, 2002 June, and 2003 February. In this section, we describe the detailed results of four campaigns separately.

3.1. The 2000 July superoutburst

The first superoutburst was noticed by P. Schmeer at 2000 July 5.941 (UT). We started observations on July 6, the day when we received the outburst report.

The long-term light curve of the 2000 July superoutburst is drawn in figure 2. The superoutburst lasted for 15 days, and QW Ser declined by an almost constant rate of 0.086 mag d^{-1} during the plateau phase. Then, the variable entered the rapid decline phase of a rate of 1.2 mag d^{-1} . While we could not detect a rebrightening, QW Ser seemed to remain about $V = 17.0$ for at least a few days after the superoutburst.

Daily light curves are shown in figure 3. The data obtained on 2000 July 6, the first night of our observations, clearly shows superhumps with an amplitude of 0.16 mag, which first proved the SU UMa nature of this dwarf nova. The superhumps had developed within 2 days from the onset of the outburst (figure 2). The amplitude of the superhumps continued to increase to 0.35 mag by July 8, and then started to decline. The amplitude, however, again developed to 0.26 mag by July 13, and seemed to decline, suggesting the timescale of the variation of the

¹ IRAF is distributed by the National Optical Astronomy Observatories for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

² (<http://www.willbell.com/aip/index.htm>)

³ (<http://munipack.astronomy.cz>)

⁴ (<ftp://ftp.nofs.navy.mil/pub/outgoing/aah/sequence/sumner/qwser.seq>)

Table 1. Log of observations.

Date			HJD-2400000	Exposure	Frame	Comp.	filter	Instrument [†]
			Start–End	Time (s)	Number	Star*		
2000	July	6	51732.334–51732.516	30	297	5	R_c	N
			51732.347–51732.431	90	64	2	R_j	P
		7	51733.299–51733.394	60	60	2	R_j	P
			51733.952–51734.082	30	62	2	V	K
		8	51734.411–51734.508	20	284	2	no	Ma
			51734.280–51734.301	60	21	2	R_j	P
			51735.077–51735.118	60	49	2	V	K
		9	51735.354–51735.482	20	380	5	no	Ma
			51735.948–51736.087	60	164	2	V	K
		11	51737.304–51737.339	60	35	2	V	P
			51737.406–51737.498	30	232	5	R_c	N
		12	51737.970–51738.035	60	77	2	V	K
			51738.296–51738.382	60	94	2	V	P
			51738.346–51738.500	50	195	5	R_c	N
		13	51739.295–51739.380	100	61	2	V	P
			51739.326–51739.509	50	230	5	R_c	N
		14	51740.284–51740.379	100	70	2	V	P
		15	51740.717–51740.790	16	240	2	no	C
			51741.281–51741.352	100	46	2	V	P
		16	51742.319–51742.394	60	85	2	R_j	P
		17	51743.330–51743.338	100	3	2	R_j	P
		18	51745.328–51745.381	100	37	2	R_j	P
		19	51746.292–51746.304	200	3	2	R_j	P
		20	51747.277–51747.315	100	21	2	R_j	P
		21	51748.356–51748.357	100	1	2	R_j	P
		23	51750.326–51750.346	200	9	2	R_j	P
		24	51751.275–51751.285	200	4	2	R_j	P
		25	51752.287–51752.302	200	5	2	R_j	P
		26	51753.287–51753.310	200	8	2	R_j	P
		27	51754.268–51754.283	200	7	2	R_j	P
		28	51755.269–51755.293	200	10	2	R_j	P
		29	51756.271–51756.279	200	4	2	R_j	P
2001	Feb.	10	51951.232–51951.349	60	135	2	V	K
		11	51951.478–51951.725	60	232	2	R_c	N
		12	51952.537–51952.764	45	232	6	R_c	N
2002	June	2	52428.078–52428.257	30	340	1	no	O25
			52428.102–52428.180	15	254	1	no	T
		3	52428.999–52429.227	14	760	2	no	M
			52429.054–52429.174	30	255	1	no	O25
			52429.092–52429.243	15	628	1	no	T
			52429.140–52429.284	30	331	1	no	O30
		4	52430.087–52430.214	30	239	1	no	O30
			52430.128–52430.236	30	193	1	no	O25
		5	52431.036–52431.178	10	1450	1	no	T
		6	52431.960–52432.059	30	200	3	V	K
			52431.991–52432.260	14	904	2	no	M
			52432.038–52432.238	30	475	1	no	O25
		7	52432.998–52433.074	30	175	3	V	K
		9	52435.028–52435.170	10	539	4	no	H
			52435.058–52435.236	10	871	1	no	T
		15	52441.020–52441.027	10	31	1	no	O30
			51441.334–52441.335	120	1	2	R_j	P
		16	52441.984–52442.000	30	29	1	no	O25
			52442.326–52442.331	120	2	2	R_j	P

Table 1. (continued)

Date	HJD-2400000	Exposure	Frame	Comp.	filter	Instrument [†]
	Start–End	Time (s)	Number	Star*		
2002 June	20 52446.315–52446.322	120	4	2	R_j	P
	21 52447.311–52447.309	60	6	2	R_j	P
	22 52448.310–52448.317	120	5	2	R_j	P
	23 52449.307–52449.312	120	3	2	R_j	P
	25 52452.308–52452.306	240	3	2	R_j	P
	29 52456.330–52456.333	120	2	2	R_j	P
July	2 52457.983–52457.990	30	15	1	no	O30
2003 Feb.	24 52695.151–52695.375	30	214	1	no	O25
	25 52696.193–52696.372	30	325	1	no	O25
	52696.169–52696.220	30	111	2	no	H
	27 52698.181–52698.346	30	307	1	no	O25
	52698.192–52698.294	40	214	2	no	K
	28 52699.135–52699.147	30	22	1	no	O25
Mar.	5 52704.153–52704.245	30	98	1	no	O25

*Comparison star 1: HD 137532 (a close double star of combined $V \sim 9.7$, noted in the Henden&Summer (H&S) sequence, 2: $V=13.411(6)$ and $B - V=0.673(4)$ in the H&S sequence (ID 4), 3: $V=11.977(8)$ and $B - V=0.946(8)$ (ID 2), 4: $V=11.770(1)$ and $B - V=0.637(4)$ (ID 1), 5: $V=13.120(12)$ and $B - V=0.722(13)$ (ID 3), 6: $V=14.599(0)$ and $B - V=0.638(5)$ (ID 7)

[†]Instrument N: 40-cm telescope + ST-7 (Brno, Czech), P: 38-cm Telescope + SBIG ST-7 (Crimea, Ukraine), K: 25-cm telescope + Apogee AP-7 (Tsukuba, Japan), Ma: 28-cm telescope + SBIG ST-7 (Ceccano, Italy), C: 44-cm telescope + Genesis 16#90 (KAF 1602e) (California, USA), O25: 25-cm telescope + SBIG ST-7/ST-7E (Kyoto, Japan), T: 30-cm telescope + SBIG ST-9E (Okayama, Japan), O30: 30-cm telescope + SBIG ST-7/ST-7E (Kyoto, Japan), M: 25-cm telescope + SBIG ST-7 (Okayama, Japan), H: 60-cm telescope + PixCellent S/T 00-3194 (SITe 003AB) (Hida, Japan)

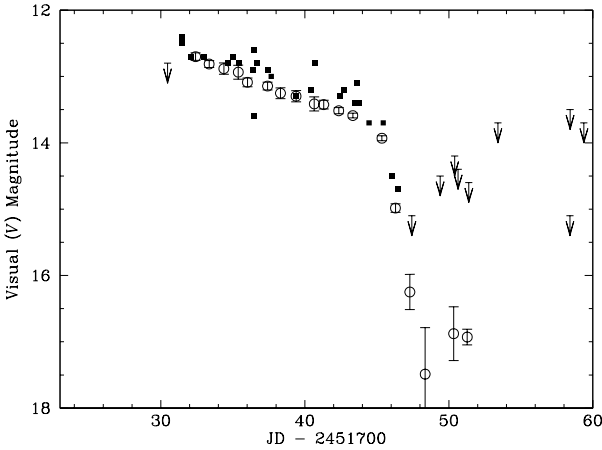


Fig. 2. Long-term light curve of the 2000 superoutburst. The filled squares and down arrows are the visual (or CCD) observations and the upper limits reported to VSNET. The abscissa is *JulianDay* – 2451700, and the ordinate is *Visual(V)magnitude*. The open circles with the error bars indicate the daily mean *V* magnitudes of our data and their standard deviations.

superhump amplitude to be 5 days. The rise of the superhump gradually but steadily became steeper by July 13, and seemed to get more gradual after that. We can not see a sign of emergence of the secondary hump until July 14, the 9th day of the superoutburst.

In the light curve of July 9, a 0.25-mag flare with a timescale of about 15 min was present before the superhump maximum around a fraction of HJD of 0.4. The light curve of a local check star relative to the comparison star did not show a special feature around that time.

After subtraction of the linear decline trend, we performed the period analysis using the Phase Dispersion Minimization (PDM) method (Stellingwerf 1978) for the data obtained in July 6–17. The resultant Θ diagram (figure 4) indicates 0.076978(8) d ($f = 12.9907(14)$ cycle d⁻¹) to be the best estimated average superhump period (P_{SH}). The error of the period was estimated using the Lafler-Kinman class of methods, as applied by Fernie (1989). The lower panel of figure 4 displays the average superhump light curve which was yielded by folding the detrended light curves by the superhump period.

The timings of the superhump maxima were extracted by fitting the average superhump light curve in figure 4. Table 2 lists the results. The cycle count was set to 1 at the first superhump maximum observed on July 6. Linear regression of the superhump maximum timings yields the following equation:

$$HJD_{\max} = 32.3210(13) + 0.076963(18) \times E. \quad (1)$$

Figure 5 and table 2 show the results of subtraction of the calculated maximum timings by equation (1) from the observed ones (O–C1). The values of O–C1 are fitted to the following quadratic polynomial:

$$O - C1 = 0.0017(5) - 1.2(1.2) \times 10^{-5}(E - 60)$$

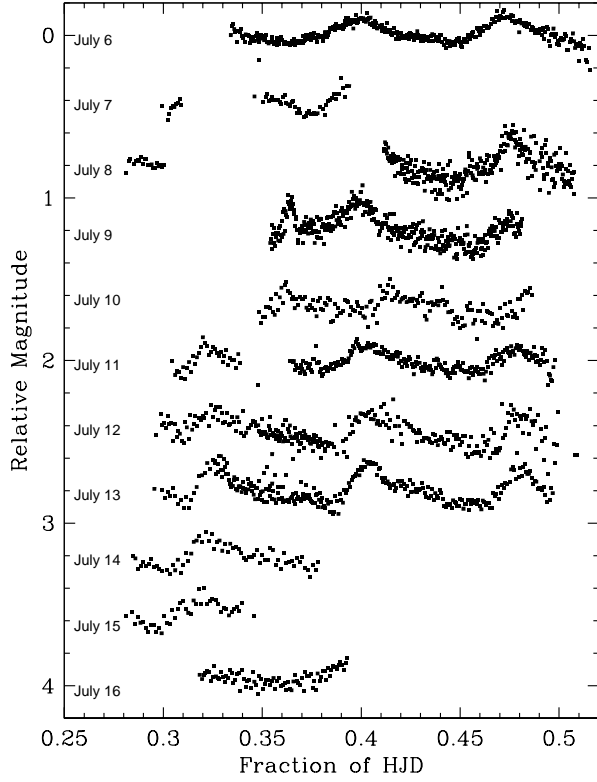


Fig. 3. Daily light curves of the 2000 superoutburst during the plateau phase. Each daily dataset is shifted by +0.4 mag. The superhump had already grown to 0.16 mag by July 6, within 2 days from the superoutburst onset. The superhump amplitude increased to 0.35 mag by July 8, then decreased. However, it again increased to 0.26 mag by July 13, then seemed to decrease again. On July 9, we can see a flare of 0.25 mag with a time scale of ~ 15 min beside a superhump maximum around a fraction of HJD of 0.4.

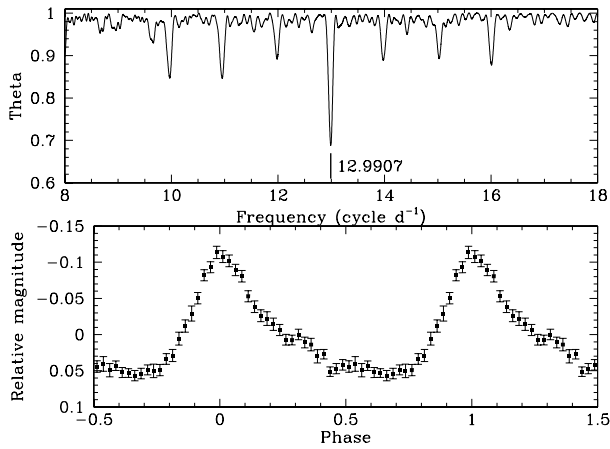


Fig. 4. (upper panel) Theta diagram obtained by a PDM period analysis for the data obtained in July 6–17. The best estimated superhump period is 0.076978(8) d (12.9908(13) cycle d^{-1}). (lower panel) The superhump light curve folded by that period.

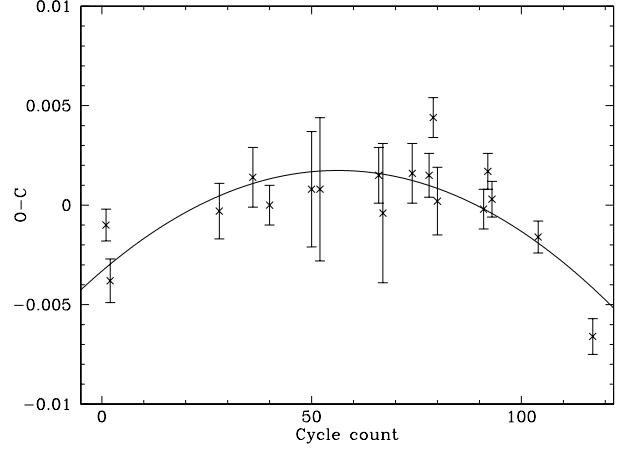


Fig. 5. O–C diagram of the superhump maximum timings during the 2000 superoutburst. The data is listed in the column O–C1 in table 2. The solid curve represents the quadratic polynomial obtained by fitting the O–C values (equation (2)), showing that the superhump period decreased with a rate of $\dot{P}_{SH}/P_{SH} = -4.2(0.8) \times 10^{-5}$.

Table 2. Timings of the superhump maxima during the 2000 July superoutburst.

HJD–2451700	E	O–C1*	O–C2†
32.3969(08)	1	–0.0010	0.0021
32.4711(11)	2	–0.0038	–0.0008
34.4756(14)	28	–0.0003	–0.0008
35.0930(15)	36	0.0014	0.0003
35.3995(10)	40	0.0000	–0.0013
36.1699(29)	50	0.0008	–0.0009
36.3238(36)	52	0.0008	–0.0009
37.4020(14)	66	0.0015	–0.0001
37.4771(35)	67	–0.0004	–0.0020
38.0178(15)	74	0.0016	0.0004
38.3256(11)	78	0.0015	0.0005
38.4054(10)	79	0.0044	0.0035
38.4782(17)	80	0.0002	–0.0006
39.3244(10)	91	–0.0002	–0.0000
39.4033(09)	92	0.0017	0.0020
39.4788(09)	93	0.0003	0.0007
40.3235(08)	104	–0.0016	0.0003
41.3190(09)	117	–0.0066	–0.0024

* Using equation (1).

† Using equation (2).

$$-1.6(0.3) \times 10^{-6}(E - 60)^2. \quad (2)$$

This curve is also drawn in figure 5. The derived index of the quadratic term means that the superhump period decreased with a rate of $\dot{P}_{SH}/P_{SH} = -4.2(0.8) \times 10^{-5}$. Note that the superhump period seemed constant in $E = 35$ –95.

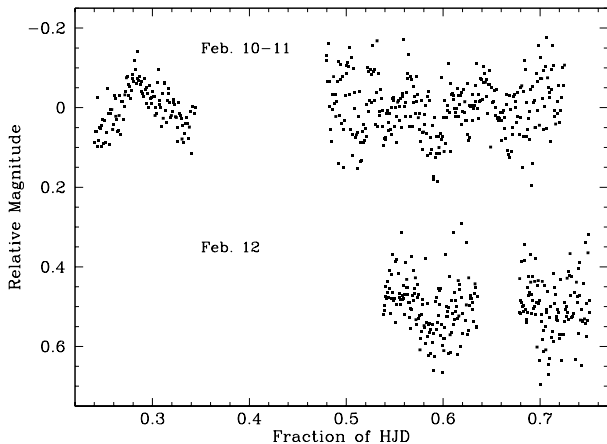


Fig. 6. Short-term light curves of the 2001 February outburst. Each daily dataset is shifted by +0.5 mag. Although the errors were not so small, superhumps certainly existed, proving that this outburst is a genuine superoutburst.

3.2. The 2001 February superoutburst

The data available via the VSNET data browser⁵ around the 2001 February superoutburst are 13.2 mag at 2001 January 25.229 (UT), 16.9 mag at 30.86 (UT), and 13.5 mag at February 12.46 (UT). No upper-limit was reported to VSNET during this period. We carried out time-resolved photometry on February 10, 11, and 12. All the data are represented in figure 6. We can see obvious superhumps above the noise level of each dataset. Thus this outburst was surely a superoutburst. The positive detection on January 25 was probably a precursor of this superoutburst.

3.3. The 2002 June superoutburst

This outburst was caught by Rod Stubbings at 2002 May 29.410 (UT) at $m_{\text{vis}} = 13.2$. We started follow-up observations 5 days later. The long-term light curve is presented in figure 7. QW Ser faded with a rate of 0.13 mag d^{-1} between HJD 2452428 and 2452433, but appeared to remain at the same brightness between HJD 2452433 and 2452435. After the superoutburst lasted 14 days, QW Ser remained about $V \sim 17.0$ for at least two weeks.

The superhumps were caught in all the dataset of each night (figure 8). We subtracted a linear decline trend of 0.13 mag d^{-1} from the plateau-phase data, and corrected the second-order color effect of each night run. After this pre-whitening, we analyzed the data by the PDM method. The resultant Θ diagram and the averaged superhump light curve are in figure 9. The best estimated superhump period of $0.076967(13) \text{ d}$ is equal to that in the 2000 superoutburst within the statistical error.

The superhump maximum timings were measured in the way for the 2000 superoutburst, and listed in Table 3. The cycle count was set to 1 at the first superhump maximum observed on June 2. The equation deduced by

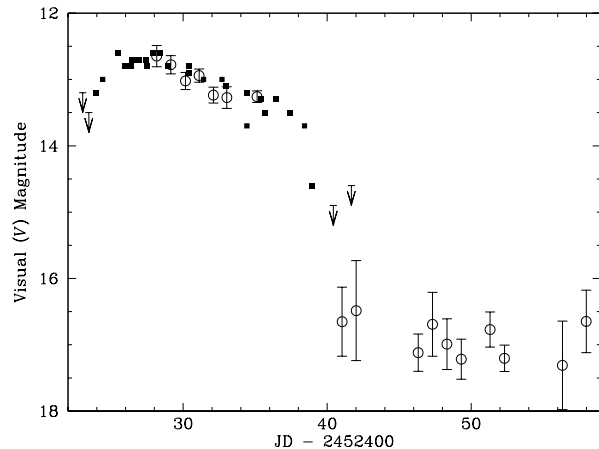


Fig. 7. Long-term light curve of the 2002 superoutburst, as figure 2.

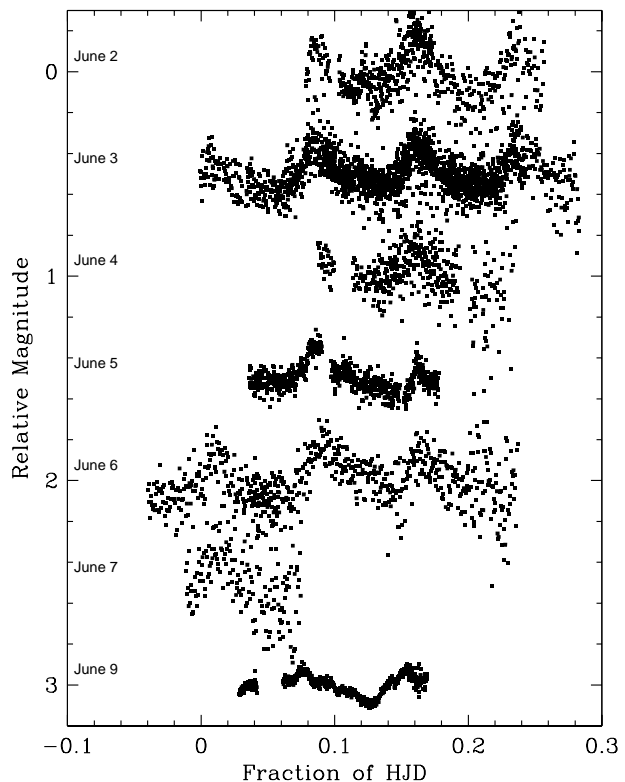


Fig. 8. Short-term light curves of the 2002 June outburst during the plateau phase. Each daily dataset is shifted by +0.5 mag.

⁵ (<http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/etc/searchobs.html>)

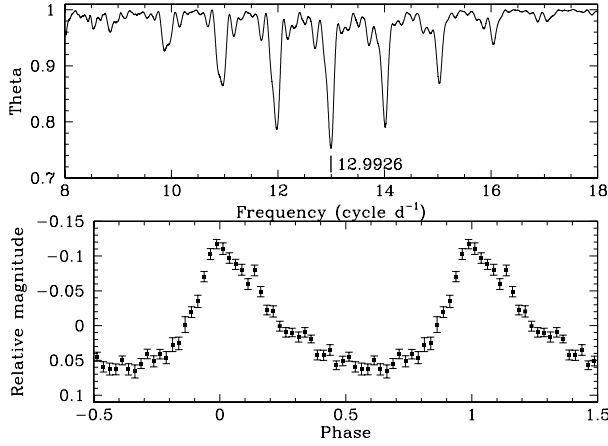


Fig. 9. (upper panel) Theta diagram obtained by a PDM period analysis for the data obtained in 2002 July 2–9. The best estimated superhump period is 0.076967(13) d (12.9926(22) cycle d⁻¹). (lower panel) The superhump light curve folded by that period.

Table 3. Timings of the superhump maxima during the 2002 June superoutburst.

HJD-2452400	E	O-C3*	O-C4†
28.1587(14)	1	-0.0012	0.0017
28.3459(32)	2	-0.0009	0.0018
29.0834(08)	13	0.0007	0.0010
29.1581(09)	14	-0.0015	-0.0014
29.2357(15)	15	-0.0008	-0.0009
30.1533(21)	27	-0.0060	-0.0078
31.0836(08)	39	0.0015	-0.0012
32.0085(24)	51	0.0036	0.0009
32.0902(23)	52	0.0084	0.0057
32.1631(25)	53	0.0044	0.0017
35.0760(25)	91	-0.0049	-0.0021
35.1550(25)	92	-0.0028	0.0002

* Using equation (3).

† Using equation (4).

linear regression of the superhump maximum timings is

$$HJD_{\max} = 28.1598(13) + 0.076900(41) \times E. \quad (3)$$

Figure 10 and table 3 show the results of subtraction of the calculated maximum timings by equation (3) from the observed ones (O-C3). Fitting of the O-C3 by a quadratic polynomial converges to

$$O - C3 = 0.0028(16) + 0.2(3.3) \times 10^{-5}(E - 46) - 2.8(1.2) \times 10^{-6}(E - 46)^2. \quad (4)$$

This curve is also drawn in figure 10. The P_{SH} decrease rate calculated from the index of the quadratic term in this equation is $\dot{P}_{\text{SH}}/P_{\text{SH}} = -7.3(3.1) \times 10^{-5}$. This rate is negative, which is indicative of the P_{SH} decrease, and consistent with that observed during the 2000 superoutburst within the error.

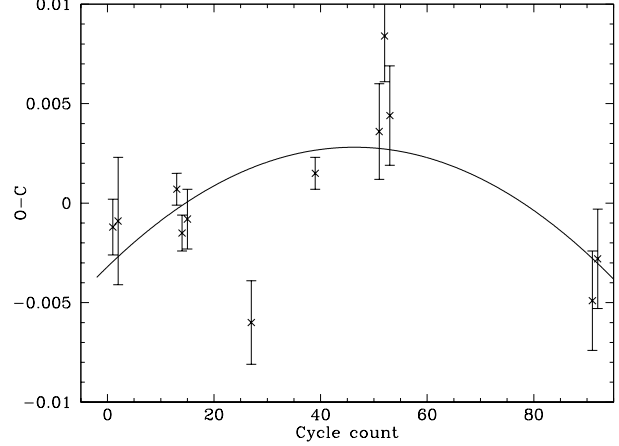


Fig. 10. O-C diagram of the superhump maximum timings during the 2002 superoutburst. The data is listed in the column O-C3 in table 3. The solid curve represents the quadratic polynomial obtained by fitting the O-C values (equation (4)), showing that the superhump period decreased with a rate of $\dot{P}_{\text{SH}}/P_{\text{SH}} = -7.3(3.1) \times 10^{-5}$.

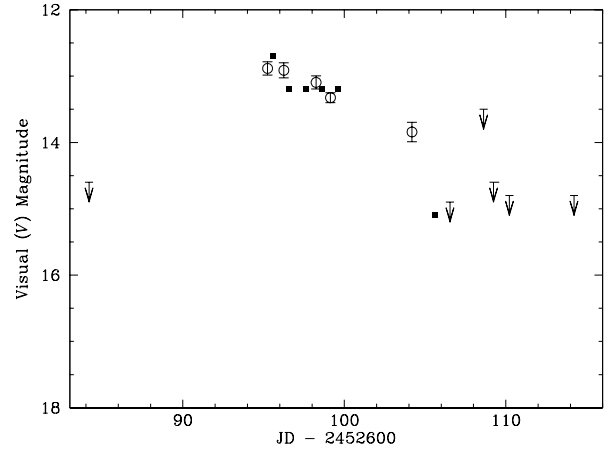


Fig. 11. Long-term light curve of the 2003 superoutburst, as figure 2.

3.4. The 2003 February superoutburst

Following the outburst detection ($m_{\text{vis}} = 12.6$) by E. Muyliaert at 2003 February 23.215 (UT), we started photometric observations on February 24.

Figure 11 exhibits the long-term light curve of the 2003 July superoutburst. The decline rate derived our data was 0.11 mag d⁻¹. Then, the variable entered the rapid decline phase of a rate of 1.2 mag d⁻¹.

After prewhitening in the same way as for the data of the 2002 superoutburst, we performed the period analysis using the PDM method for the data obtained on February 24, 25, and 27 (figure 12). Although the short coverages of each dataset hinder us from distinguishing the true signal from its aliases, we can safely choose the genuine P_{SH}

Table 4. Previous outbursts.

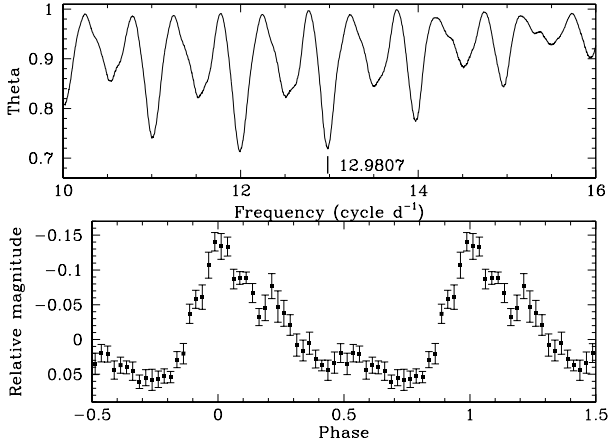


Fig. 12. Theta diagram for the data obtained in February 24–27 (upper panel), and the averaged superhump light curve (lower panel), as figure 4. Due to the short coverages of each run, the periodogram suffers from an alias problem. However, we can safely choose 0.07704(4) d (12.981(6) cycle d⁻¹) as the best estimated P_{SH} , because of those in the other superoutbursts.

of 0.077037(37) d ($f = 12.9807(62)$ cycle d⁻¹) from the superhump periods during the other superoutbursts. The lower panel of figure 12 presents the average superhump light curve during our observations of this superoutburst.

The superhump maximum timings observed were insufficient to significantly deduce the change rate of P_{SH} .

4. Discussion

Table 4 summarizes the outbursts reported in Takamizawa 1998 and to VSNET and those detected by the All Sky Automated Survey (Pojmanski 2002). As the maximum magnitude of the 1999 superoutburst (12.2 mag) is suspected to be due to inaccuracy of magnitudes of comparison stars in a finding chart the observer used, the true superoutburst maximum should be around $V = 12.5$. Thus the superoutburst amplitude is ~ 5.0 mag. The maximum magnitude of the normal outburst is $V \sim 13.1$. The recurrence cycle of the normal outburst seems to have been rather stable around 50 days. If we assume that a superoutburst was missed around 2001 September, the recurrence cycle of the superoutburst (supercycle) has been also stable, about 220–270 d since 1999, while SU UMa stars showing variable outburst patterns have recently been discovered, such as MN Dra (Nogami et al. 2003b), DI UMa (Fried et al. 1999), SU UMa (Rosenzweig et al. 2000; Kato 2002), V1113 Cyg (Kato 2001), V503 Cyg (Kato et al. 2002a), and DM Lyr (Nogami et al. 2003a). The change rate of the superhump period was $-4.2(0.8) \times 10^{-5}$ during the 2000 superoutburst and $-7.3(3.1) \times 10^{-5}$ during the 2002 superoutburst. They agree with each other within the error.

The superhump period of 0.0770 d is near the mode of the P_{SH} distribution (see e.g. Kolb, Baraffe 1999; Kato et al. 2003a). The delay of the superhump emergence

	Date*		V_{max}	D^{\dagger}	Type [‡]	Comment
1994	Sep. 25		12.8p			Single Obs.
1994	Dec. 29		14.8p			Single Obs.
1998	Apr. 02		12.8p			Single Obs.
1999	Oct. 04	12.2		>11	S	
2000	May 05	14.9		2	N	
2000	Jul. 05	12.4		15	S	
2001	Jan. 25	13.2		1?	N	
2001	Feb. 08	13.5		>5	S	
2001	Apr. 29	13.2		2?	N	
2001	Jun. 18	13.7		2?	N	
2001	Aug. 10	13.1		1?	N	
2002	Mar. 21	13.1		2	N	
2002	May 16	13.9:			N?	Single Obs.
2002	May 29	12.7		15	S	
2002	Aug. 01	13.2		2	N?	
2002	Aug. 08	13.4				Single Obs.
2003	Feb. 25	12.7		>10	S	
2003	Mar. 15	13.1		<3	N	Single Obs.
2003	Jun. 22	13.1		3	N	

* The discovery date.

† Duration of the outburst in a unit of day.

‡ N: normal outburst, S: superoutburst.

was constrained to be within 2 days during the 2000 July superoutburst. This short delay is in accordance with the relatively long superhump period (see e.g. table 1 in Osaki 1996). All the values of the amplitude of the superoutburst, these outburst cycles, the P_{SH} change rate, the superhump delay, the decline rates of 0.09–0.13 mag d⁻¹ during the plateau phase and of 1.2 mag d⁻¹ during the rapid decline phase are typical values for an SU UMa star having $P_{\text{SH}} = 0.07700$ d (see (Nogami et al. 1997; Kato et al. 2003b; Warner 1995b)). Note that we did not detect a significant change in the decline rate throughout the plateau phase, in contrast to that this rate is expected to become smaller with depletion of the gas in the outer disk (Cannizzo 2001).

We can here estimate the distance to QW Ser by applying the relation between the orbital period (P_{orb}) and the absolute maximum brightness proposed by Warner (1987). The superhump period is used instead of P_{orb} , since the orbital period of QW Ser has not yet been measured and the superhump period is known to be only a few percent longer than P_{orb} . The error introduced by this is much smaller than other factors. Since the lack of eclipses in the light curve means that the inclination is not so high, the inclination effect to the observed flux (Warner 1986) should be negligible. The absolute maximum magnitude is thus expected to $M_V = 5.2 \pm 0.2$ from the Warner’s relation. Then the distance is estimated to be 380 (± 60) pc, taking into account that this maximum magnitude should be compared to the apparent maximum magnitude of the normal outburst in the case of SU UMa-type dwarf novae

(cf. Kato et al. 2002b; Cannizzo 1998). This distance is smaller than the secure upper limit estimated using the proper motion of QW Ser and the maximum expected velocity dispersion of CVs (Harrison et al. 2000).

The X-ray luminosity in the range of 0.5–2.5 keV can be guessed to be $\log L_X = 31.0 \pm 0.1$ from the ROSAT data and the distance, making use of the formulation given by Verbunt et al. (1997). This luminosity is a little higher than, but not far from the average value of SU UMa stars, which is consistent with that QW Ser has typical properties for an SU UMa-type dwarf nova in other points.

The authors are very thankful to amateur observers for continuous reporting their valuable observations to VSNET. Thanks are also to the anonymous referee for useful comments. We used the data obtained by the All Sky Automated Survey project which are kindly opened into public. This work is partly supported by a Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists (MU and RI), and a grant-in-aid from the Japanese Ministry of Education, Culture, Sports, Science and Technology (No. 13640239, 15037205).

References

- Cannizzo, J. K. 1998, *ApJ*, 493, 426
 Cannizzo, J. K. 2001, *ApJL*, 561, L175
 Fernie, J. D. 1989, *PASP*, 101, 225
 Fried, R. E., Kemp, J., Patterson, J., Skillman, D. R., Retter, A., Leibowitz, E., & Pavlenko, E. 1999, *PASP*, 111, 1275
 Harrison, T. E., McNamara, B. J., Szkody, P., & Gilliland, R. L. 2000, *AJ*, 120, 2649
 Kato, T. 2001, *Inf. Bull. Variable Stars*, 5110
 Kato, T. 2002, *A&A*, 384, 206
 Kato, T., Ishioka, R., & Uemura, M. 2002a, *PASJ*, 54, 1029
 Kato, T., Nogami, D., Moilanen, M., & Yamaoka, H. 2003a, *PASJ*, in press (astro-ph/0307064)
 Kato, T. et al. 2003b, *MNRAS*, 339, 861
 Kato, T., & Uemura, M. 1999, *Inf. Bull. Variable Stars*, 4802
 Kato, T., Uemura, M., Matsumoto, K., Garradd, G., Masi, G., & Yamaoka, H. 2002b, *PASJ*, 54, 999
 Kazarovets, E. V., Samus, N. N., & Durlevich, O. V. 2000, *Inf. Bull. Variable Stars*, 4870
 Kolb, U., & Baraffe, I. 1999, *MNRAS*, 309, 1034
 Nogami, D., Baba, H., Matsumoto, K., & Kato, T. 2003a, *PASJ*, 55, 483
 Nogami, D., Masuda, S., & Kato, T. 1997, *PASP*, 109, 1114
 Nogami, D. et al. 2003b, *A&A*, 404, 1067
 Osaki, Y. 1996, *PASP*, 108, 39
 Pojmanski, G. 2002, *Acta Astron.*, 52, 397
 Rosenzweig, P., Mattei, J., Kafka, S., Turner, G. W., & Honeycutt, R. K. 2000, *PASP*, 112, 632
 Schmeer, P. 1999, *vsnet-alert*, 3548⁶
 Stellingwerf, R. F. 1978, *ApJ*, 224, 953
 Takamizawa, K. 1998, *VSOLJ Variable Star Bull.*, 30, 3
 Truss, M. R., Murray, J. R., & Wynn, G. A. 2001, *MNRAS*, 324, 1P
 Verbunt, F., Bunk, W. H., Ritter, H., & Pfeffermann, E. 1997, *A&A*, 327, 602
 Voges, W. et al. 2000, *IAU Circ.*, 7432
 Warner, B. 1985, in *Interacting Binaries*, ed. P. P. Eggleton & J. E. Pringle (Dordrecht: D. Reidel Publishing Company), 367
 Warner, B. 1986, *MNRAS*, 222, 11
 Warner, B. 1987, *MNRAS*, 227, 23
 Warner, B. 1995a, *Cataclysmic Variable Stars* (Cambridge: Cambridge University Press)
 Warner, B. 1995b, *Ap&SS*, 226, 187
 Whitehurst, R. 1988, *MNRAS*, 232, 35

⁶ (<http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert3000/msg00548.html>)